

METHOD AND APPARATUS FOR CONTROLLING RADIATION BEAM
INTENSITY DIRECTED TO MICROLITHOGRAPHIC SUBSTRATES

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application relates to material disclosed in U.S. Application No. _____ (attorney docket number 10829.8543US) titled "Method and Apparatus for Irradiating a Microlithographic Substrate," filed on August 30, 2001 and incorporated herein in its entirety by reference.

BACKGROUND

[0002] The present invention is directed toward methods and apparatuses for controlling the intensity of a radiation beam directed toward a microlithographic substrate. Microelectronic features are typically formed in microelectronic substrates (such as semiconductor wafers) by selectively removing material from the wafer and filling in the resulting openings with insulative, semiconductive, or conductive materials. One typical process includes depositing a layer of radiation-sensitive photoresist material on the wafer, then positioning a patterned mask or reticle over the photoresist layer, and then exposing the masked photoresist layer to a selected radiation. The wafer is then exposed to a developer, such as an aqueous base or a solvent. In one case, the photoresist layer is initially generally soluble in the developer, and the portions of the photoresist layer exposed to the radiation through patterned openings in the mask change from being generally soluble to become generally resistant to the developer (e.g., so as to have low solubility). Alternatively, the photoresist layer can be initially generally insoluble in the developer, and the portions of the photoresist layer exposed to the radiation through the openings in the mask become more soluble. In either case, the portions of the photoresist layer that are

resistant to the developer remain on the wafer, and the rest of the photoresist layer is removed by the developer to expose the wafer material below.

[0003] The wafer is then subjected to etching or metal disposition processes. In an etching process, the etchant removes exposed material, but not material protected beneath the remaining portions of the photoresist layer. Accordingly, the etchant creates a pattern of openings (such as grooves, channels, or holes) in the wafer material or in materials deposited on the wafer. These openings can be filled with insulative, conductive, or semiconductive materials to build layers of microelectronic features on the wafer. The wafer is then singulated to form individual chips, which can be incorporated into a wide variety of electronic products, such as computers and other consumer or industrial electronic devices.

[0004] As the size of the microelectronic features formed in the wafer decreases (for example, to reduce the size of the chips placed in electronic devices), the size of the features formed in the photoresist layer must also decrease. In some processes, the dimensions (referred to as critical dimensions) of selected features are evaluated as a diagnostic measure to determine whether the dimensions of other features comply with manufacturing specifications. Critical dimensions are accordingly selected to be the most likely to suffer from errors resulting from any of a number of aspects of the foregoing process. Such errors can include errors generated by the radiation source and/or the optics between the radiation source and the mask. The errors can also be generated by the mask, by differences between masks, and/or by errors in the etch process. The critical dimensions can also be affected by errors in processes occurring prior to or during the exposure/development process, and/or subsequent to the etching process, such as variations in deposition processes, and/or variations in material removal processes, such as chemical-mechanical planarization processes.

[0005] One general approach to correcting lens aberrations in wafer optic systems (disclosed in U.S. Patent No. 5,142,132 to McDonald et al.) is to reflect the incident radiation from a deformable mirror, which can be adjusted to correct for the aberrations in the lens optics. However, correcting lens aberrations will not

generally be adequate to address the additional factors (described above) that can adversely affect critical dimensions. Accordingly, another approach to addressing some of the foregoing variations and errors is to interpose a gradient filter between the radiation source and the mask to spatially adjust the intensity of the radiation striking the wafer. Alternatively, a thin film or pellicle can be disposed over the mask to alter the intensity of light transmitted through the mask. In either case, the filter and/or the pellicle can account for variations between masks by decreasing the radiation intensity incident on one portion of the mask relative to the radiation intensity incident on another.

[0006] One drawback with the foregoing arrangement is that it may be difficult and/or time-consuming to change the gradient filter and/or the pellicle when the mask is changed. A further drawback is that the gradient filter and the pellicle cannot account for new errors and/or changes in the errors introduced into the system as the system ages or otherwise changes.

SUMMARY

[0007] The present invention is directed to methods and apparatuses for controlling the intensity distribution of radiation directed to microlithographic substrates. In one aspect of the invention, the method can include directing a radiation beam from a radiation source along radiation path, with the radiation beam having a first distribution of intensity as a function of location in a plane generally transverse to the radiation path. The method can further include impinging the radiation beam on an adaptive structure positioned in the radiation path, and changing an intensity distribution of the radiation beam from the first distribution to a second distribution different than the first distribution by changing a state of a first portion of the adaptive structure relative to a second portion of the adaptive structure. The method can further include directing the radiation beam away from the adaptive structure along the radiation path and impinging the radiation beam directed away from the adaptive structure on the microlithographic substrate.

[0009]

[10829-8547/SL012120.001]

[0010] In a further aspect of the invention, the adaptive structure can include a selectively transmissive medium having a first portion aligned with a first portion of the radiation beam when the radiation beam is emitted from the radiation source, and a second portion aligned with the second portion of the radiation beam. Each of the first and second portions can have a transmissivity that is changeable from a first transmissivity to a second transmissivity different than the first transmissivity. Alternatively, the adaptive structure can include a reflective medium having a first portion aligned with a first portion of the radiation beam when the radiation beam is emitted from the radiation source, and a second portion aligned with a second portion of the radiation beam. Each of the first and second portions of the reflective medium can be coupled to at least one actuator to move from a first inclination angle relative to the radiation path to a second inclination angle relative to the radiation path, with the second inclination angle being different than the first inclination angle.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Figure 1 is a partially schematic view of an apparatus for irradiating microlithographic substrates in accordance with an embodiment of the invention.

[0012] Figure 2 is a partially schematic view of a portion of an adaptive structure that includes a reflective medium and a diffuser plate in accordance with an embodiment of the invention.

[0013] Figure 3 is a partially schematic view of an adaptive structure that includes a reflective medium and a diffuser plate in accordance with another embodiment of the invention.

[0014] Figure 4 is a partially schematic view of an adaptive structure that includes a selectively transmissive medium in accordance with yet another embodiment of the invention.

[0015] Figure 5 is a flow chart illustrating a method for adjusting characteristics of radiation directed toward a microlithographic substrate in accordance with an embodiment of the invention.

[0016] Figures 6A-6C are flow diagrams illustrating details of methods for adjusting the radiation directed toward microlithographic substrates in accordance with further embodiments of the invention.

DETAILED DESCRIPTION

[0017] The present disclosure describes methods and apparatuses for controlling the intensity of radiation directed toward a microlithographic substrate. The term "microlithographic substrate" is used throughout to include substrates upon which and/or in which microelectronic circuits or components, data storage elements or layers, vias or conductive lines, micro-optic features, micromechanical features, and/or microbiological features are or can be fabricated using microlithographic techniques. Many specific details of certain embodiments of the invention are set forth in the following description and in Figures 1-6C to provide a thorough understanding of these embodiments. One skilled in the art, however, will understand that the present invention may have additional embodiments, and that the invention may be practiced without several of the details described below.

[0018] Figure 1 schematically illustrates an apparatus 110 for controllably irradiating a microlithographic substrate 160 in accordance with an embodiment of the invention. The apparatus 110 can include a radiation source 120 that directs an electromagnetic radiation beam 128 along a radiation path 180 toward the microlithographic substrate 160. The apparatus 110 can further include an adaptive structure 140 that adjusts the intensity distribution of the incoming radiation beam 128. Optionally, the radiation beam 128 can then pass through a lens system 123 configured to shape and/or magnify the radiation emitted by the source 120. Optionally, the apparatus 110 can further include a diffractive element 122 to diffuse the radiation, and a light tube 124 positioned to generate a plurality of images of the radiation source 120. The light tube 124 and/or or a sizing lens 125 can size the radiation beam 128, which can then be directed by a mirror 126 through a focusing lens 127 to a reticle or mask 130 along a reticle radiation path segment 181a.

[0019] The reticle 130 can include reticle apertures 131 through which the radiation passes to form an image on the microlithographic substrate 160. The radiation passes through a reduction lens 139 which reduces the image pattern defined by the reticle to a size corresponding to the size of the features to be formed on the microlithographic substrate 160. The radiation beam 128 then travels in a second direction 182 along a substrate radiation path segment 182a, and impinges on a radiation-sensitive material (such as a photoresist layer 161) of the microlithographic substrate 160 to form an image on the layer 161. In one embodiment, the beam 128 impinging on the layer 161 can have a generally rectangular shape with a width of from about 5 mm. to about 8 mm. and a length of about 26 mm. In other embodiments, the beam 128 incident on the layer 161 can have other shapes and sizes. In one embodiment, the radiation can have a wavelength in the range of about 157 nanometers or less (for example, 13 nanometers) to a value of about 365 nanometers or more. For example, the radiation can have a wavelength of about 193 nanometers. In other embodiments, the radiation can have other wavelengths suitable for exposing the layer 161 on the microlithographic substrate 160.

[0020] The microlithographic substrate 160 is supported on a substrate support 150. In one embodiment (a scanner arrangement), the substrate support 150 moves along a substrate support path 151, and the reticle 130 moves in the opposite direction along a reticle path 132 to scan the image produced by the reticle 130 across the layer 161 while the position of the radiation beam 128 remains fixed. Accordingly, the substrate support 150 can be coupled to a support actuator 154 and the reticle 130 can be coupled to a reticle actuator 137.

[0021] As the reticle 130 moves opposite the microlithographic substrate 160, the radiation source 120 can flash to irradiate successive portions of the microlithographic substrate 160 with corresponding successive images produced by the reticle 130, until an entire field of the microlithographic substrate 160 is scanned. In one embodiment, the radiation source 120 can flash at a rate of about 20 cycles during the time required for the microlithographic substrate 160 to

move by one beam width (e.g., by from about 5 mm. to about 8 mm.). In other embodiments, the radiation source 120 can flash at other rates. In any of these embodiments, the radiation source 120 can flash at the same rate throughout the scanning process (assuming the reticle 130 and the substrate 150 each move at a constant rate) to uniformly irradiate each field. Alternatively, the radiation source 120 can deliver a continuous radiation beam 128. In either embodiment, each field can include one or more dice or chips, and in other embodiments, each field can include other features.

[0022] In another embodiment (a stepper arrangement), the radiation beam 128 and the reticle 130 can expose an entire field of the microlithographic substrate 160 in one or more flashes, while the reticle 130 and the substrate support 150 remain in a fixed transverse position relative to the radiation path 180. After the field has been exposed, the reticle 130 and/or substrate support 150 can be moved transverse to the radiation path 180 to align other fields with the radiation beam 128. This process can be repeated until each of the fields of the microlithographic substrate 160 is exposed to the radiation beam 128. Suitable scanner and stepper devices are available from ASML of Veldhoven, The Netherlands; Canon USA, Inc., of Lake Success, New York; and Nikon, Inc. of Tokyo, Japan.

[0023] In a further aspect of this embodiment, a controller 170 is operatively coupled to the reticle 130 (or the reticle actuator 137) and the substrate support 150 (or the support actuator 154). Accordingly, the controller 170 can include a processor, microprocessor or other device that can automatically (with or without user input) control and coordinate the relative movement between these elements. The controller 170 can also be coupled to the adaptive structure 140 to control the intensity distribution of the radiation beam 128, as described in greater detail below.

[0024] Figure 2 is a schematic view of the adaptive structure 140 described above with reference to Figure 1 in accordance with an embodiment of the invention. In one aspect of this embodiment, the adaptive structure 140 can include a reflective

medium 141, a grating 144, and a diffuser 148, all positioned along the radiation path 180. The reflective medium 141 can include a two-dimensional array of movable reflective elements 142 (four of which are shown schematically in Figure 2 as elements 142a-d), coupled to a corresponding plurality of actuators 143 (shown as actuators 143a-d). For example, the reflective medium 141 can include a digital multi-mirror device, such as a device available from Texas Instruments of Dallas, Texas. Accordingly, each reflective element 142 can form a portion of a larger reflective surface 149 and can move independently of the other reflective elements. The interstices between the reflective elements 146 can be filled with a reflective (or optionally, a non-reflective) material that allows for relative movement of adjacent elements 142.

[0025] The reflective elements 142 direct the radiation beam 128 to the grating 144. In one embodiment, the grating 144 can include first portions or regions 145 (shown as first regions 145a-d) positioned between second portions or regions 146 (shown as second regions 146a-d). In one embodiment, the first regions 145 can be opaque and the second regions 146 can be transparent. In other embodiments, the first and second regions 145, 146 can have other transmissivities for which a first transmissivity of the first regions 145 is less than a second transmissivity of the second regions 146. In one embodiment, the first regions 145 can be formed by a rectilinear grid of lines disposed on an otherwise transparent (or at least more transmissive) substrate, such as quartz. In other embodiments, the first regions 145 can have other shapes and arrangements. In any of these embodiments, the first regions 145 can intersect some of the radiation directed by the reflective medium 141 toward the grating 144 to locally reduce the intensity of the radiation passing through the grating 144. In a further aspect of this embodiment, the first regions 145 can have an absorptive coating 147 facing toward the reflective medium 141 to prevent the intersected radiation from reflecting back toward the reflective medium 141.

[0026] The diffuser 148 receives the radiation passing through the grating 144 and smoothes what might otherwise be discrete shadows or discontinuities in the

[0027] In operation, each of the reflective elements 142 of the reflective medium 141 can be positioned to direct portions of the impinging radiation beam 128 (which has an initial, generally uniform intensity distribution across the section of the beam) in a selected manner to produce a different intensity distribution. For example, element 142b can be positioned to direct a radiation beamlet 128b directly between two first regions 145b and 145c to produce an undeflected level of intensity, as indicated by line 182. Elements 142c and 142d can be positioned to direct radiation beamlets 128c and 128d, respectively, directly toward first region 145d. Accordingly, the radiation reflected by these elements will have a reduced intensity, as is also shown by line 182. The reflective element 142a can be positioned to direct a radiation beamlet 128a that illuminates less than the entire corresponding first region 145a to produce a level of intensity that is less than that produced by element 142b, but greater than that produced by elements 142c and 142d. Similar adjustments can be made to the entire array of reflective elements 142 to selectively tailor the intensity distribution to a selected level.

[0028] In one embodiment, the resolution of the changes in intensity distribution shown in Figure 2 can be relatively coarse in comparison to the individual features produced on the microlithographic substrate 160 (Figure 1). For example, the microelectronic or other microlithographic features formed in the microlithographic substrate 160 can have dimensions on the order of less than one micron, while the distance between adjacent portions of the radiation beam 128 having different intensities can be from about 0.3 mm. to about 1 mm. or greater. In one embodiment, the shift in intensity can be less than about 10% of the undeflected intensity of the radiation beam 128 (e.g., less than about 10% of the intensity incident on the reflective medium 141). In other embodiments, the maximum deviation in intensity from any portion of the radiation beam 128 to any other portion can be less than about 5% of the incident intensity, and in a specific

embodiment, can be from about 1% to about 2% of the incident intensity. Accordingly, the grating 144 can have an open area of about 90 percent in one embodiment, and can have a greater open area in other embodiments.

[0029] Figure 3 is a partially schematic illustration of another embodiment of the adaptive structure 140 described above with reference to Figure 2. In one aspect of this embodiment, the adaptive structure 140 does not include a grating 144. Accordingly, the reflective elements 142a-d can direct corresponding radiation beamlets 128a-d at different angles directly to the diffuser 148. The diffuser 148 can smooth out transitions between regions of the radiation beam 128 having different intensities (generally as described above) to produce a radiation distribution line 382. In one aspect of this embodiment, the radiation beamlets 128c and 128d can combine to produce a local intensity greater than the undeflected intensity. One advantage of the arrangement shown in Figure 3 when compared to the arrangement shown in Figure 2 is that the overall intensity of the radiation beam shown in Figure 3 can be greater than that shown in Figure 2 because the grating 144 (which can absorb a portion of the radiation) is eliminated. Conversely, an advantage of the arrangement shown in Figure 2 is that the grating 144 can provide an added degree of control over the reflected radiation beam 128 (for example, it may dampen the effect of system vibrations), when compared to an arrangement that includes the diffuser 148 alone.

[0030] Figure 4 is a partially schematic illustration of an adaptive structure 440 having a mirror 483 that directs the radiation beam 128 to impinge on a variably transmissive medium 480. The variably transmissive medium 480 can include a liquid crystal material arranged to form variably transmissive elements 481 (shown in Figure 4 as elements 481a-c). The variably transmissive elements 481 can be coupled to a source of electrical power and can be reversibly changed from one transmissive state to another, within a range of transmissivities that can vary from transparent or nearly transparent to opaque or nearly opaque. For example, the variably transmissive elements 481a can be selected to be transparent or at least approximately transparent to pass a portion of the radiation beam 128 through the

[0031] In other embodiments, the adaptive structure 440 can have other arrangements. For example, the variably transmissive medium 480 can include materials other than a liquid crystal material. In another alternate embodiment, the variably transmissive medium can include a single, continuously variable element in place of the plurality of elements described above. In any of the foregoing embodiments, the adaptive structure 440 can adjust the intensity of the radiation beam to the levels and resolutions described above with reference to Figure 2.

[0032] Figure 5 is a flow diagram illustrating steps of a method for using any of the apparatuses described above with reference to Figures 1-4 in accordance with an embodiment of the invention. Figures 6A-6C illustrate further details of the steps shown in Figure 5. Beginning with Figure 5, a method 500 can include irradiating a microlithographic substrate with a radiation beam having a selected intensity distribution to form an image on the microlithographic substrate (step 502). The method can further include forming features in the microlithographic substrate based on the image formed in step 502 (step 504). In step 506, characteristics of the features formed in the microlithographic substrate are compared with target characteristics. In step 508, the process includes determining whether the characteristics of the features are within pre-selected limits. If the characteristics are within the limits, the process ends. If not, the configuration or setting of the

adaptive structure is adjusted in step 510, and the process is repeated with a different microlithographic substrate.

[0033] Figure 6A illustrates details of an embodiment of the process for forming features in the microlithographic substrate based on the image formed with the radiation beam (step 504). In one aspect of this embodiment, the process can further include developing the image in a photoresist layer (step 602). The material beneath the photoresist layer can be selectively etched to form recesses (step 604). The recesses can be filled with a conductive, semiconductive, or non-conductive material (step 606). Once the recesses have been filled, excess material can be removed from the microlithographic substrate, for example, by chemical-mechanical planarization, in step 608.

[0034] Figure 6B illustrates further details of embodiments of the process for comparing characteristics of features in the microlithographic substrate with target characteristics (step 506). In step 610, the process can include selecting the features of the microlithographic substrate. For example, the features can include control structures specifically formed in the microlithographic substrate for diagnostic purposes. Alternatively, the process can include selecting other structures of the microlithographic substrate, such as features configured to be operated by the end user. In still a further embodiment, the features can include features formed in a photoresist layer prior to etching or depositing materials on the microlithographic substrate. In any of these embodiments, the process can include comparing measured feature dimensions with target values for the same dimensions (step 612). In a specific aspect of this process, the method can include analyzing the features with an electron microscope and comparing the measured results with target results. In another embodiment (step 614), the method can include comparing the conductivity of one or more features with a target conductivity. In any of the foregoing embodiments, the process of comparing characteristics of microelectronic or other microlithographic features with target characteristics can be repeated until an entire die is checked (step 616) and/or until an entire field and/or wafer is checked (step 618). The process

can also be carried out on a plurality of wafers or other microlithographic substrates.

[0035] Figure 6C illustrates details of an embodiment of the process of adjusting the setting of the adaptive structure (step 510). For example, when the adaptive structure includes tiltable or otherwise moveable reflective elements, the process can include adjusting the inclination angle of the reflective elements relative to the radiation path (step 620). Alternatively, for example, when the adaptive structure includes variably transmissive elements, the process can include adjusting the transmissivity of selected transmissive elements (step 622). In either embodiment, the process can further include replacing an initial microlithographic substrate with a subsequent microlithographic substrate after the adjustment (step 624), for example, to determine the effect of the adjustment.

[0036] One feature of the arrangements described above with reference to Figures 1-6C is that the adaptive structures can be easily altered by providing instructions from the controller 170. An advantage of this feature is that unlike conventional filters and pellicles, the structure that tailors the intensity of the radiation need not be removed from the system and replaced in order to produce a new intensity distribution. Accordingly, this arrangement can be less expensive than conventional arrangements because it requires fewer pieces of hardware. The arrangement can also be more efficient than conventional arrangements because it can take less time to change the intensity distribution of the radiation beam.

[0037] Another advantage of the arrangements described above with reference to Figure 1-6C is that they can be used to account for a wide range of factors that can systematically cause characteristics of the microelectronic or other microlithographic features to deviate from their target characteristics. For example, the adaptive structure can be adjusted to account for slight variations across a given mask and/or between different masks or reticles that are configured to produce the same illumination pattern on one or more microlithographic substrates, but that may fail to do so due to manufacturing

tolerances or errors. Alternatively, the adaptive structure can be used to account for the degradation that can occur to a single mask and/or other system optics and/or the radiation source over the course of time. Still further, the adaptive structure can tailor the intensity distribution of the incident radiation beam to correspond to a variety of different masks having a wide variety of disparate aperture patterns. For example, the adaptive structure can have a first configuration when used with a first mask to form one type of microelectronic die or chip, and can be changed to a second configuration when used with a second mask to form a different type of microelectronic die or chip.

[0038] In other embodiments, the adaptive structure can be used to account for variations produced by other aspects of the process or processes for forming microelectronic devices or other microlithographic features. For example, if a particular section of the microlithographic substrate or microlithographic substrate field tends to etch more slowly than another (producing features that are undersized), the intensity of the radiation directed to this region can be increased. The increased radiation can locally increase the radiation dose and therefore the size of the features formed in that region. If one region of the microlithographic substrate has a non-uniform optical thickness as a result of prior material deposition and/or removal processes (such as CMP processes), this can alter the manner in which the radiation-sensitive material subsequently disposed on the microlithographic substrate behaves. For example, optically non-uniform regions may reflect incident radiation differently than uniform regions, which can change the amount of reflected radiation absorbed by the photoresist layer on the microlithographic substrate. The intensity distribution of the radiation directed toward this portion of the substrate can be altered to account for this non-uniformity, for example by increasing the incident radiation intensity where the radiation absorption is less than a target level, and/or decreasing the incident radiation intensity where the radiation absorption is greater than a target level.

[0039] From the foregoing, it will be appreciated that specific embodiments of the invention have been described herein for purposes of illustration, but that various

modifications may be made without deviating from the spirit and scope of the invention. For example, in one embodiment, the apparatus can include both a deformable reflective medium and a variably transmissive medium to increase the degree of control over the intensity of the radiation exiting the adaptive structure. In another embodiment, any of the refractive elements described above, including the reticle, can be replaced with reflective elements that perform generally the same function. Accordingly, the invention is not limited except as by the appended claims.

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